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THE DEVELOPMENT OF A REAL-TIME DECIMETER-LEVEL POSITIONING SYSTEM USING GLOBAL POSITIONING SYSTEM (GPS) TECHNOLOGY

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ABSTRACT

The U.S. Army Corps of Engineers spends in excess of \$350 million annually dredging the nation's ports, harbors and waterways. An additional \$40 million is spent performing hydrographic surveys supporting the planning, engineering and design phases of this effort. The U.S. Army Engineer Topographic Laboratories (USAETL) has been tasked, under the U.S. Army Corps of Engineers Dredging Research Program (DRP), to develop a real-time decimeter-level positioning system using Global Positioning System (GPS) technology to support the Corps hydrographic surveying and dredging operations. This paper will discuss USAETL's Research and Development (R&D) efforts involved in the development of this positioning system.

INTRODUCTION

The U.S. Army Corps of Engineers spends millions of dollars annually dredging the nation's ports, harbors and waterways. Many more millions are spent performing hydrographic surveys in support of this dredging mission. Presently, dredges and hydrographic survey vessels are horizontally positioned with systems in either a range range, redundant range, or range azimuth mode. Typical accuracies of one meter are obtainable using these methods. These systems generally require calibration at a known point every day, and shore stations must be installed at controlled survey sites. The calibration process and maintenance of these control stations are extremely expensive and labor intensive. Also, dredging and surveying operations are vertically referenced to the vessel performing the work. Current technology does not allow surveyors to accurately define the height of the vessel relative to a datum at a specific job site.

With the deployment of the Navigation Satellite Timing and Ranging (NAVSTAR) Global Positioning System (GPS), a possibility for effi-

cient, highly accurate, three-dimensional positioning of moving vessels in the marine environment has materialized.

USAETL has been tasked, under the U.S. Army Corps of Engineers Dredging Research Program (DRP), to develop a real-time decimeter-level positioning system using GPS technology to support the Corps dredging and hydrographic surveying operations. The DRP is a seven-year program launched during Fiscal Year 1988 (FY88) to address problems and needs arising in the performance of the Corps dredging mission. The DRP is divided into five major problem areas consisting of 23 work units.

GPS OVERVIEW

GPS is being implemented and operated by the U.S. Department of Defense (DOD) to provide continuous, all weather navigation and positioning capabilities anywhere in the world. The present constellation of satellites consist of six operational Block I satellites and six operational Block II satellites. There will be a total of 21 Block II satellites with 3 on-orbit spares in the full constellation. The Block II satellites are being launched on a Delta II rocket at a rate of approximately one every 60 days.

Each satellite transmits signals on two L-Band frequencies, L1 and L2. The L1 carrier frequency is 1575.42 MHz and has a wavelength of approximately 19 centimeters (cm). The L2 carrier frequency is 1227.60 MHz and has a wavelength of approximately 24 cm. The L1 signal is modulated with a Precision (P) code and a Coarse Acquisition (C/A) code while the L2 signal is modulated with only the P code. These codes are referred to as pseudo-random noise (PRN) codes and serve as a very precise time reference that permit ground receivers to compute the time of transmission of the satellite signal. Each satellite carries very precise atomic clocks to generate timing information needed for

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precise positioning. A navigation message is also transmitted on both frequencies. This message contains ephemerides, clock behaviors, health and status of satellites, almanacs and other general information.

Measurements of position can be made with GPS using any one of several different techniques that use the PRN codes and/or carrier frequencies. A single measurement from any satellite based on either the P or C/A code is referred to as a "pseudorange." A pseudorange is nothing more than the distance measurement between the satellite and the ground receiver antenna plus some unknown error. Each distance measurement implies the receiver is somewhere on the surface of a sphere centered at the satellite with radius equal to the distance measurement. Assuming the satellite positions are known, based on the broadcast or precise ephemeris, a three-dimensional position of the ground receiver antenna can be computed at any specific epoch when four or more satellites are observed simultaneously. This technique is referred to as absolute point positioning. The final positional accuracies obtainable using this technique varies from ± 15 meters when using the P code, to ± 100 meters using the C/A code. DOD has announced the anti-spoofing or encryption of the P code, thus making it available for select users only. It is also DOD's intent to create a Selective Availability with the C/A code to degrade its positional accuracy to the ± 100 meter level. Absolute point positioning accuracies are not sufficient for performing dredge positioning and hydrographic surveying.

Another technique used to compute a receiver's position is referred to as differential pseudorange. In differential pseudorange, the position of a moving vessel or object station is found relative to a reference station located on a known control monument. Pseudoranges are collected and pseudorange corrections are computed at the reference station and transmitted to the object station. The pseudorange corrections are then applied to the pseudoranges collected at the object station to compute the final position of the object station. This technique is very robust and is an ideal technique for dynamic positioning. Many GPS receivers are designed for dynamic applications when performing position computations using the code observables. In the event of loss of lock on a satellite, the positioning accuracy is readily regained with reacquisition of the satellite signal. The major drawback of this technique is its accuracy. Tests have shown accuracies of about five meters with baselines up

to several hundred kilometers in length.

To obtain the highest precision from GPS, two or more receivers are used in the relative mode and vectors between the two receivers are computed by processing carrier phase measurements. This technique involves tracking the same carrier phase measurements at each receiver. Either the L1, L2 or both carrier signals can be used in this technique. Current receiver electronics allow the signal phase to be measured to a precision of about one millimeter (mm). However, these measurements are ambiguous, leaving the integer cycle ambiguities as unknowns to be solved. By recording simultaneous observations at multiple receivers, signal differencing techniques can be used to process the data to obtain the vector between receivers. These techniques allow several error sources to be eliminated as well as solving for the integer cycle ambiguities. As long as lock is maintained on a minimum of four satellites, the integer cycle ambiguities are also maintained, therefore allowing the vector to be computed very accurately between two receivers. If loss of lock occurs, and a sufficient number of satellites are not being tracked to maintain the initial integer cycle ambiguities, some form of reinitialization procedure needs to be performed to acquire new integers. This is the major technical problem that needs to be resolved in order to use this technique to position moving vessels. The initialization procedures are very simple when this technique is used in a static mode. Sitting stationary for a long period of time, performing an antenna swap, and making observations over a known baseline are all typical initialization procedures. However, these are not practical for use in positioning moving vessels, thus requiring further R&D in overcoming this problem. The accuracy of this technique is approximately one cm + two parts-per-million (ppm) of the baseline distance when the integer cycle ambiguities can be solved and maintained. This accuracy makes the technique very attractive for dredge positioning and hydrographic surveying.

USAETL'S R&D

USAETL'S researchers began the DRP work unit by writing system requirements for the real-time decimeter-level positioning system. These system requirements were based on the technical and accuracy needs of the Corps' hydrographic and dredging operations. A dynamic positioning system meeting or exceeding these requirements can actually perform the following tasks:

1. Provide the vertical reference to an on-site tide gage to establish offshore dredging datums. These gages would only remain on-site temporarily. GPS could then be used to re-establish the datum in the future because it would be the positioning system on-board the survey boat or dredge.

2. Provide vertical reference to a survey boat or dredge at the project site.

3. Provide horizontal positions to a survey boat or dredge.

The major advantages of a GPS-based positioning system are:

1. No calibration would be required prior to a survey.

2. Only one shore station would be needed for a relatively large geographic area.

3. For the first time ever, it would be possible to accurately relate soundings to a dredging datum, even when operating several kilometers offshore.

For a GPS-based positioning system to be successful, it must meet several minimum requirements. It must provide horizontal positional accuracies equivalent to that obtained with existing positioning systems (\pm one meter). Existing water surface modeling techniques using on-site gages can provide vertical accuracies of about 0.2 meters; however, these are not repeatable at this level due to meteorological and hydrological conditions. Therefore, the system should be capable of redefining the vertical datum at the 0.1 meter level. It is anticipated that if the accuracy of 0.1 meters in the vertical can be achieved, the horizontal accuracy will be on the same order since the vertical component of GPS has the worst accuracy. The scale of surveys require positions to be computed at least once a second and provided to other on-board systems when the event actually occurred, or a time delay must be provided for matching soundings and positions. True real-time positions must be provided to an accuracy of several meters for mission navigation.

A study was performed for USAETL by the University of New Brunswick to determine the feasibility of developing a real-time decimeter-level positioning system. This study also provided a detailed descriptive analysis of work being performed by industry addressing decimeter-level positioning with GPS. Among the topics covered

were the technical constraints which affect high accuracy kinematic GPS positioning, siting and operation of reference stations, hardware and software requirements, problems transferring GPS antenna positions to other points of interest on the vessel, the requirements for a data communications link and problems of data synchronization. The expected performance from four possible methods of using GPS for high accuracy differential positioning were also discussed. These four methods were as follows:

1. Use of code pseudoranges only.

2. Use of code pseudoranges and carrier phases.

3. Use of carrier phase double differences, ambiguities resolved a priori.

4. Use of carrier phase double differences, ambiguities resolved on the fly.

The study revealed that a production level system capable of producing decimeter-level differential positioning for dredging and hydrographic surveying operations is not available. The system must be capable of either pseudoranging with an accuracy of several centimeters, or resolving the carrier phase ambiguities on the fly. Instantaneous pseudoranging at centimeter accuracy seems not to be feasible; therefore, a method to solve for integer cycle ambiguities needs to be developed. Initial studies indicate this will only be achievable by combining improved P code pseudoranges with carrier phase measurements. Differential ionospheric delays need to be considered as a major error source if the separation between the reference station and the vessel is going to be of any long distance (>50 kilometers). Dual frequency GPS systems will probably be required to solve for these delays, thus minimizing any error. The feasibility of successfully developing a real-time decimeter-level system depends on solving problems in the areas of pseudorange noise, multipath, selective availability, and the determination of integer cycle ambiguities after loss of lock or cycle slips.

Tests and data analyses are being performed in-house at USAETL to verify and test operational procedures and new technical concepts. A field test was performed at Holloman Air Force Base on a high-speed sled track to verify the potential for using GPS carrier phase measurements to position a moving platform at the decimeter level. The sled track is a rail track approximately 10 miles in length which has very precisely

surveyed interrupter blades located every few feet along the track. As a sled passes each of these blades, a light beam mounted on the sled is broken. Each time this beam is broken, a signal is radioed to a master site so a time mark can be entered for recovery of the position at a later time. This system is called the Velocity Measuring System (VMS) and the final output from the VMS is time, Universal Time Coordinated (UTC), and distance along the track.

A C/A code receiver and antenna were mounted on the sled. Reference receivers were located on known survey monuments at each end of the track and all receivers simultaneously observed the same satellites during the test. The GPS measurements were postprocessed to obtain positions relative to the reference receivers. The distances between interrupter blades as computed from the GPS positions were compared to the distances measured by the VMS. Comparisons at the couple centimeter level were produced. Although, there were operational problems during the test, the results indicate that decimeter-level positioning of a moving platform can be accomplished using GPS.

A second field test was performed in the Corps of Engineers Norfolk District, aboard a hydrographic survey boat, to determine operational problems and constraints using GPS for positioning a moving vessel on open waters. During this test, three C/A code receivers and antennae were placed aboard a 65 foot survey boat. One antenna was on the bow, one on the stern, and one in the middle on top of the cabin. Another receiver was located on the boat dock and the last receiver was on a known survey monument in the vicinity of the dock. Antenna swaps were performed at the beginning of each day between each of the three boat antennae and the antenna that stayed stationary on the dock. This allowed fast and easy acquisition of the initial integer cycle ambiguities. Upon completion of the antenna swaps, each of the three boat antennae were carefully moved to the boat. The fourth receiver and antenna remained on the dock as a reference receiver. Three days were spent collecting carrier phase data while the boat was operating on the open water. One of these days, a simulated hydrographic survey was performed and positioning data were gathered from both GPS and a tellurometer line-of-sight positioning system. During the last day of the test, the survey boat anchored approximately 430 feet from a tide gage at the Chesapeake Bay Bridge/Tunnel. GPS and tide gage measurements were recorded for approximately 42 minutes for comparison at

a later date. All GPS data were manually processed and analyzed. The boat positions computed using GPS are relative to the antennae located on the dock and the known survey monument.

Initial results show a fairly large bias between the tellurometer and GPS when used for horizontal positioning. The bias is very evident, however the trends exhibited by the graphed latitude and longitude produced from the GPS data are similar to those of the tellurometer. Comparison of the GPS data with the tide gage readings show a deviation between the two of less than 10 centimeters during the 42-minute observation period. The largest deviation was towards the end of the observation period. This can probably be attributed to only four satellites being available and the poor geometry of these satellites during this time.

An in-house data link analysis is being performed to examine various alternatives for providing communications or data link between a reference station and the dredge or survey boat. A high speed data link will probably be required because of the large amount of raw GPS measurements that need to be transmitted in a short period of time (one second).

A systems analysis is currently being performed under contract. The purpose of this systems analysis is to develop alternate system designs; prepare detailed descriptions of selected systems; analyze and simulate system performance; quantify system error bounds and operational goals; and prepare a decision matrix for the selection of a "best" system. A full benefit/cost analysis will be performed to aid the Corps in determining the most cost effective system that will meet the technical and operational goals for dredge positioning and hydrographic surveying.

FUTURE ACTIVITIES

Upon completion of the systems analysis contract, specifications will be developed to award a contract to design and build a fully operable prototype positioning system that can be tested and demonstrated. These specifications will be based on the findings from the systems analysis contract and data link analysis, as well as knowledge obtained from in-house testing. The prototype system will include all components to make the system fieldable. This will include all the GPS hardware, data link, software, and computers.

The final phase of this project involves testing and demonstrating the prototype system. Present plans call for system demonstrations beginning in November, 1993. Testing will be performed to determine the full capabilities and operational procedures of the system. Operation manuals will be written to provide the best and most efficient procedures for the system. Demonstrations will be held to allow government and industry personnel to observe the operation of the system.

CONCLUSION

Several government and industry researchers are currently addressing individual technical issues needed to successfully develop and build a fully operable real-time decimeter-level positioning system using GPS technology. Although such a system does not exist today, results from research efforts are showing great promise for the future. By the time the full constellation of satellites is in orbit, real-time decimeter-level positioning of dredges and hydrographic survey vessels will be a reality.

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